Effect of Different Onset Thresholds on Isometric Mid-Thigh Pull Force-Time Variables

ABSTRACT

Various thresholds have been used to identify the onset of contraction during isometric mid-thigh pull (IMTP) however, no agreed onset threshold exists for this assessment. The purpose of this study was to compare relative body weight (BW) and arbitrary onset thresholds to a criterion onset threshold 5 SD of BW for IMTP force-time variables; force at each threshold, peak force (PF), time-specific force values (100, 150 and 200 ms) and rate of force development (RFD) during 0-100 ms, 0-150 ms, 0-200 ms. Academy rugby league players (n = 9, age: 18.5 ± 0.4 years; height: 1.82 ± 0.09 m; mass: 91.2 ± 13.1 kg) performed two IMTP trials on a force platform sampling at 1000 Hz. The neutral force-time data pool (18 trials) was analyzed with five different thresholds and compared to criterion threshold to determine any variance in force-time variables. 5 SD of BW was significantly lower than 10% BW and 75N for threshold force which led to significantly greater time specific force values at 100 and 150 ms and unacceptable limits of agreements (LOA) for all force-time variables. No significant differences ($p>0.05$) were observed between 2.5% and 5 SD of BW; and between 5% and 5 SD of BW for threshold force and all force-time variables with acceptable LOA. The 5 SD of BW and 2.5% BW onset thresholds consistently resulted in the lowest values for threshold force, time-specific force values and RFD, attributed to a lower onset bias. Therefore, scientists and practitioners are recommended to use a 5 SD of BW onset threshold for time-specific force values and RFD for accurate data because it accounts for signal noise during the weighing period. Subsequently, there is greater certainty that the onset of contraction identifies a true meaningful change in force, in contrast to relative BW thresholds.

KEY WORDS: Time-specific Force; Rate of Force Development; Force-time data, Phase Identification; Onset bias

INTRODUCTION

Neuromuscular performance of the lower limbs can be evaluated based on analysis of force-time data generated during dynamic or isometric tasks such as vertical jumps (VJ) (26-28), isometric mid-thigh pulls (IMTP) (13, 27, 35) or isometric squats (2, 16). Peak force (PF) and peak rate of force development (RFD) are commonly analyzed from force-time data (3, 12, 22) and often demonstrate high reliability (12, 24) and low measurement error (6, 35). The IMTP induces minimal fatigue and is time efficient compared to dynamic one repetition maximum testing (1RM). Additionally, nearly perfect correlations ($r \geq 0.96$) have been reported between IMTP PF and 1RM back squat performance (24, 25). Importantly, the IMTP can be used to monitor the effectiveness of training interventions, fatigue and neuromuscular preparedness, but may also be used as a tool for talent identification (11).

Distinctive advantages of IMTP assessments are that an athlete's ability to express force rapidly can be assessed by examining time-specific force, RFD and impulse values during critical time periods (30-300 ms) (3, 6, 7, 12). Conversely, maximal dynamic strength assessments such as 1RM back squat and power cleans fail to provide this insight, highlighting the specific advantages of monitoring neuromuscular performance via the IMTP. Not only have time specific-force values, RFD and impulse during specific epochs demonstrated high reliability (6, 12, 34), these variables have also been associated with dynamic tasks including sprint (34, 36), change of direction speed (34) and jumping performance (21). This could be attributed to the similarity of the contact times and force application periods for these dynamic tasks (26, 32, 37).

One problem that currently compromises the accuracy of IMTP force-time data is how the start point of force-time data analysis is identified (8, 9, 23, 26). This is explained by noise associated with such analyses connected with electronic equipment, ambient noise from electromagnetic radiation, movement artifact and inherent stability of the signal (26). More importantly, participant posture and any associated movement, can potentially impact the noise during body weight (BW) weighing periods and therefore subsequent thresholds derived from such weighing periods (8, 23); although this can be minimized with strict instructions to participants and visual inspection of the force-time data during data collection. It is recommended that IMTP trials where there is an unstable baseline force during the weighing period (uncontrolled pre tension and visible countermovement) should be rejected and another trial performed (23). Selecting a start threshold too low may result in early triggering of the onset of contraction and may result in elevations of force-time variables, such as time to PF and movement time, which have been reported during countermovement jumps (8, 26). Similarly, selecting a threshold too high would result in a delayed onset of contraction known as onset bias (0 ms point) resulting in underestimations of variables such as movement time, time to PF and elevations of force-time variables such as force, RFD and impulse at pre-determined time points (8, 14, 23). Therefore, it is imperative that strict and well administered IMTP testing is completed and that onset of contraction threshold identifies and reflects the start of contraction for accurate measures of force-time variables.

Various thresholds have been used to identify the onset of contraction and start point for force-time data analysis so that time-specific force values, RFD and impulse during various phases can be calculated. However, a generally accepted method to determine the onset of contraction in IMTP testing does not exist, which renders comparison of IMTP force-time values from different studies problematic. For example, previous studies have used arbitrary values of 20 N (19), 40 N (6) and 75 N(7), when calculating force-time variables. Although it should be noted that higher thresholds to determine the onset of contraction may result in onset bias, where there is a time delay bias in the identification of the onset of contraction and could lead to misinterpreted and erroneous calculations of force-time variables (8, 23). Biases of approximately 20 ms (30) to as much as 330 ms (31) have been reported as a result of objective threshold determined onsets. West et al. (36) determined their starting threshold when 5 standard deviations (SD) of instantaneous rate of change of force with respect to time (1 second stationary) was exceeded. Conversely, many have failed to define how they identified the start of the contraction (0 ms) for force-time variables (3, 12, 20, 21, 29, 34), which makes it difficult to replicate force-time data analysis procedures and evaluating the accuracy of previous research findings (8).

Various onset thresholds have been used for VJ assessments (9), including arbitrary force values (33), relative measures of BW (26), 5 SD of BW (28, 36), manual selection (15) and relative change in power (10). Researchers have compared the effects of different start thresholds on kinetic and kinematic variables during jump assessments and shown that the different thresholds produce significantly different kinetic and kinematic values (9, 14, 26). The 5 SD of BW is considered the gold standard for onset of contraction identification in vertical jump assessments as this method takes into account the noise associated during the weighing period (28, 36). Body weight is defined as the average vertical ground reaction force (VGRF) during 1 second of stance (28). The onset of movement is defined as the point in which the VGR, after a signal to jump had been given, exceeded BW plus or minus 5 SD (28). As such, a deviation in force that exceeds 5 SD of BW is almost certainly a meaningful change in force which demonstrates the onset of contraction (start of jump). In light of this, the 5 SD of BW may be an appropriate method to determine the onset of contraction during

IMTP assessments, however this has yet to be investigated. Consequently, scientists and practitioners require information regarding the effect of different onset of contraction thresholds on IMTP force-time variables to allow accurate assessments of neuromuscular performance which reflect the athlete's ability to apply force rapidly.

The aim of this study was to examine whether commonly used onset thresholds, 2.5% BW [$BW_{2.5}$], 5% BW [BW_5], 10% BW [BW_{10}] and (75N [BW_{75N}]) agreed with the gold standard threshold of 5 SD of BW (BW_{5SD}) for time-specific force values and RFD (0-100 [RFD_{100}], 0-150 [RFD_{150}] and 0-200 [RFD_{200}] ms). It was hypothesized that BW_{75N} and BW_{10} thresholds would result in significantly higher resultant values for all force-time variables than BW_{5SD} and demonstrate unacceptable agreement. It was also hypothesized no significant differences in force-time variables would be found between BW_{5SD} $BW_{2.5}$, and BW_5 thresholds demonstrating acceptable agreement.

METHODS

Experimental approach to the problem

A repeated measures, within-subjects design was used to determine the effect that the onset threshold had on PF, force at and RFD during 100, 150 and 200 ms. Subjects performed two maximum effort IMTPs while standing on a force plate sampling at 1000 Hz. Force-time data were pooled (18 trials), analyzed using a customized analysis spreadsheet, and the effect of the different onset thresholds in force-time variables were studied.

Subjects

Professional academy rugby league players (n = 9, age: 18.5 ± 0.4 years; height: 1.82 ± 0.09 m; mass: 91.2 ± 13.1 kg) provided informed consent to participate in this study, which was approved by the university ethics committee. Subjects were familiar with the IMTP and were experienced with weightlifting movements (≥2 years weight training experience); all IMTP trials were assessed by certified strength and conditioning specialists. At the time of testing subjects were in the second week of their preseason mesocycle.

Procedures

Pre-isometric assessment warm up

All subjects performed a standardized warm up comprised of five minutes of dynamic stretching before advancing to dynamic mid-thigh clean pulls. One set of five repetitions was performed with an empty barbell (Werksan Olympic Bar, Werksan, Moorsetown, NJ, USA) followed by three isometric efforts at a perceived intensity of 50, 70, and 90% of maximum effort, interspersed with a one-minute recovery.

Isometric mid-thigh pull protocol

The IMTP procedures were in accordance to previous research and have been reported previously(7). Briefly, subjects performed a total of two maximal effort trials lasting five seconds and interspersed with a two-minute rest period (34); if the difference between the two trials exceeded 250 N then a third trial was performed (3). Verbal encouragement was given for all trials and subjects. Subjects were instructed to be as still as possible, without initiating a pull on the bar for at least 1 second prior to the instructions to 'pull', to permit calculation of body weight based on the associated force-time data. Trials that did not have a stable baseline force trace (peak deviation > 50 N from average BW) were rejected along with trials with a visible countermovement, subsequently another trial was performed (23). Ground reaction force data was sampled at 1000 Hz for eight seconds via a portable force platform (Kistler, Switzerland, Model 9286AA, SN 1209740) interfaced with a laptop and recorded using Bioware software (Version 5.11; Kistler Instrument Corporation, Switzerland).

Isometric force-time curve assessment

All force-time data recorded during the IMTP were analyzed using a customized analysis spreadsheet to determine specific force-time characteristics. The maximum force generated during the five second maximum effort IMTP was reported as the absolute PF (12). Additionally, time-specific force values ($Force_{100}$, $Force_{150}$ and $Force_{200}$) and RFD during 0-100, 0-150 and 0-200 ms (RFD_{100}, RFD_{150} and RFD_{200}) from the onset thresholds (onset of the contraction/pull) were determined for each trial. This was in accordance with previous studies that have utilized similar pre-determined time bands when calculating force and RFD while demonstrating high reliability (3, 12, 21). Specifically, RFD was calculated using the equation: RFD = Δforce/Δtime interval. This equation was applied to the time bands 0-100, 0-150 and 0-200 ms, respectively (3, 12). These time intervals were selected based on typical ground contact times experienced during dynamic movements such as jumping, sprinting and changing direction (26, 32, 37). For this reason time bands <100 ms were not selected.

Five onset thresholds were implemented and compared to explore the effects of different thresholds on IMTP force-time variables. The criterion onset threshold and onset of the contraction (referred as time point 0 ms) was defined as force exceeded 1) 5 SD from BW (BW_{5SD}) (28, 36). The other onset thresholds were compared against the criterion method and were defined as point when 2) force exceeded 2.5% from BW ($BW_{2.5}$) (26), 3) force exceeded 5% from BW (BW_{5}) (26), 4) force exceeded 10% from BW (BW_{10}) (26) and 5) force exceeded 75N from BW (BW_{75N}). The combined residual force and BW were calculated as the average force over a 1 second stationary weighing period (in mid-thigh pull position posture) prior to the initiation of the IMTP, similar to the weighing period calculations of BW during VJ assessments (28, 36).

Statistical Analyses

Statistical analyses were performed using SPSS software version 22 (SPSS, Chicago, Ill, USA) and a custom reliability spreadsheet (17). Normality for all variables was confirmed using a Shapiro Wilks-test. Within-session reliability was assessed via intra class coefficients (ICC), 95% confidence intervals (CI) and coefficient of variation (CV) using a custom spreadsheet (17). The CV was calculated based on the mean square error term of logarithmically transformed data (17). Minimum acceptable reliability was determined with an ICC >0.7 and CV <15% (1, 12). Standardized differences were calculated using Cohen's d = M1 - M2/σ pooled (5) and the scale presented by Hopkins et al. (18) used to quantify magnitude. Cohen's d effect sizes (ES) were interpreted as trivial (< 0.19), small (0.20 – 0.59), moderate (0.60 – 1.19), large (1.20 – 1.99), and very large (2.0 – 4.0) (18). The mean of the difference (bias) was expressed absolutely and as a percentage, ratio (criterion threshold / alternative threshold) and the 95% limits of agreement (LOA) (LOA: mean of the difference ± 1.96 standard deviations) were calculated between onset thresholds using methods described by Bland and Altman (4). Unacceptable LOA were determined a priori as bias percentage difference greater than ±3%. Multiple one way repeated measures analysis of variance (RMANOVA) and Bonferonni post hoc comparisons were conducted to determine if there were significant differences in the values of PF, force at and RFD over 100, 150 and 200 ms between the different onset thresholds. Statistical significance was defined $p \leq 0.05$ for all tests, with resultant p values corrected, using Bonferroni correction, to reduce the risk of a family-wise error.

RESULTS

Body weight and threshold force values demonstrated high within-session reliability measures across thresholds (Table 1). High within-session reliability was observed for all time-specific force values across all thresholds, meeting minimum acceptable reliability criteria (Table 1). The highest ICC and lowest level of variances for all RFD values were produced with a $BW_{2.5}$; all meeting minimum acceptable reliability criteria (Table 1). Conversely, greater level of variances were observed with the other thresholds for RFD_{150} and RFD_{200} exceeding the thresholds for acceptable CV (Table 1).

Descriptive statistics and observed power for all force-time variables for each threshold are presented in Table 2. Pairwise comparisons between thresholds for force-time variables are presented in Table 3. In addition, bias, ratio and LOAs are presented for all variables in Tables 4 & 5.

Insert Table 1 around here

Insert Table 2 around here

The onset threshold used to identify the start of force-time data analysis did not affect body weight or peak force ($p=1.000$). Conversely, onset threshold had a significant effect on threshold force ($p<0.05$) (Table 3). BW_{5SD} threshold force was significantly lower ($p<0.05$) than BW_{10} threshold force and BW_{75N} with very large differences and unacceptable LOA (Tables 3 & 4). Conversely, no significant differences for $BW_{2.5}$ and BW_{5} when compared to BW_{5SD} were observed ($p>0.05$) however higher threshold forces value were observed in comparison to $BW_{2.5}$ with large effect sizes and unacceptable LOA (Tables 3 & 4). BW_{5SD}

produced lower threshold force values in comparison to BW_5 with small effect sizes and unacceptable LOA.

No significant differences were observed for BW_{5SD} when compared to $BW_{2.5}$ and BW_5 for all time-specific force values and RFD with trivial effect sizes and acceptable LOA (Tables 3 & 4). BW_{5SD} was Significantly different to $BW_{10;}$ and BW_{75N} for all time-specific force values with trivial to small effect sizes (Table 3). Unacceptable LOA for Force100 and Force150 was also demonstrated (Table 4).

Insert table 3 around here

Insert table 4 around here

RFD was not significantly different for all onset thresholds when compared to the criterion threshold BW_{5SD} ($p>0.05$). Trivial effect sizes and acceptable LOA were demonstrated with thresholds $BW_{2.5}$ and BW_5 when compared to the criterion method (Table 5). Trivial to small effect sizes and greater biases were revealed with thresholds BW_{10} and BW_{75N} when compared to the criterion method with unacceptable LOA observed for RFD_{150} (Table 5)

Insert table 5 around here

Insert Figure1around here

DISCUSSION

The aims of the study were to assess the agreement of commonly used onset thresholds in comparison to a criterion threshold for force-time variables. Firstly, all threshold force, and time specific-force values achieved minimum acceptable reliability criteria with all onset thresholds comparable to previous research (3, 7, 21). However, RFD_{150} and RFD_{200} values demonstrated acceptable reliability criteria with $BW_{2.5}$ only (Table 1). The results of this study revealed significant large to very large differences (Table 3) in force threshold values for onset thresholds BW_{10} and BW_{75N} when compared to the criterion method. Subsequently, this led to trivial to small significant differences in time-specific force values and unacceptable LOA (Tables 3 & 4). Conversely, $BW_{2.5}$ and BW_5 demonstrated acceptable LOA in comparison to the criterion onset threshold with differences between values trivial and non-significant (Tables 3 & 4). No significant differences were observed for BW, PF and RFD between onset thresholds compared to criterion threshold, however trivial to small differences in RFD values were found (Table 3) for BW_{10} and BW_{75N} and larger biases which could still be practically meaningful to practitioners and scientists when monitoring changes in RFD. Moreover, the onset threshold impacts the threshold force value and subsequent time-specific force and RFD values, with table 3 demonstrating differences in values ranging from trivial to small for force-time variables and small to very large for the threshold force value. These findings are in agreement with previous research which have shown the method to identify the start of a movement or contraction subsequently influences force-time values (8, 9, 14, 23, 26). Scientists and practitioners are therefore encouraged to keep the threshold of determining the onset of contraction consistent across testing sessions to allow valid comparisons of force-time variables when monitoring and tracking changes in neuromuscular performance.

Insert Figure 2 around here

Insert Figure 3 around here

Various thresholds have been stated for IMTP assessments (6, 7, 19, 36) whereas previous studies have failed to state how they defined the start for force-time variable analysis (3, 12, 20, 21, 29, 34) making it difficult to replicate force-time data analysis procedures. This study to our knowledge is the first to examine the effect of different onset thresholds on IMTP force-time variables. A consistent observation from our study was the BW_{10} and BW_{75N} threshold produced higher force-time values, demonstrated greater bias and subsequently elevated values in contrast to the other onset thresholds (Tables 3-5). These elevations in time-specific force values from the BW_{10} and BW_{75N} method can be attributed to the significantly higher force threshold value and subsequent greater onset bias in comparison to $BW_{2.5}$, BW_{5SD} and BW_5 force threshold values as illustrated in Figure 1. Researchers have suggested that a higher relative or absolute threshold to determine the onset of a contraction may result in onset bias, where there is a time delay bias from the actual true contraction which can lead to misinterpreted and erroneous calculations of kinetic variables (8, 23). Subsequently, from our findings, the other onset thresholds methods in contrast to BW_{5SD}, $BW_{2.5}$ and BW_5 result in greater onset bias and this delay in force-time analysis for time-specific force values results in calculation and analysis of these values on a higher portion of the force-time curve as illustrated in Figure 1. Consequently, this resulted in inaccuracies and erroneous calculations of time-specific force values and RFD, causing the inflated values and unacceptable LOA with the criterion threshold force at 100 and 150 ms.

$BW_{2.5}$ and BW_{5SD} produced the lowest force-time values with no significant differences ($p>0.05$) in values for all kinetic variables and trivial effect sizes (Table 3). However, based on the means of this data set BW_{5SD} produced slighter greater values than $BW_{2.5}$ with biases of 34.8 - 41.2N (2.0-2.4%) observed for $Force_{100}$, $Force_{150}$ and $Force_{200}$ (Table 4), achieving acceptable LOA criteria. Conversely, Bland and Altman plots illustrated in Figure 2 indicate some individual variation in relation to the agreement between the two methods. For example, Figure 2 illustrates some BW_{5SD} trials produced lower onset threshold force and subsequent time-specific force values in comparison to $BW_{2.5}$. The individual cases where the BW_{5SD} produced lower kinetic values (Figure 2) are likely to be explained by the low noise (low standard deviation) from pre-tension/contraction and posture or residual noise during the weighing period. Conversely, the Bland and Altman plots (Figure 2) also reveal that greater values across all variables can be attained with a BW_{5SD} onset threshold which can be attributed to a greater onset threshold because of greater noise during the weighing period. A $BW_{2.5}$ threshold is not influenced by the noise associated during the weighing period which may explain the better reliability measures between trials (Table 1). Therefore, these findings suggest that a BW_{5SD} onset threshold can produce lower onset lower threshold forces and kinetic values when noise during the weighing period is minimized.

No significant differences ($p>0.05$) were observed between BW_{5SD} and BW_5 for all kinetic variables with trivial effect sizes (Table 3). Additionally, low mean bias was found between these two onset thresholds for all kinetics (Table 4 & 5); based on the mean of the data BW_5 produced slightly higher time-specific force values with mean biases of <24.4N (<1.4%) reported achieving acceptable LOA criteria (Table 4). It should be noted that narrower LOAs for all force-time variables were observed for BW_5 in contrast $BW_{2.5}$ against the criterion threshold, suggesting a better agreement (Figure 3 and Tables 4 & 5). Conversely greater mean biases were observed when comparing BW_{5SD} to BW_{10} and BW_{75N} which did not meet acceptable LOA criteria for force at and RFD during 100 and 150 ms (Tables 4 & 5). Scientists and practitioners are therefore advised not to use BW_{10} relative threshold and

BW_{75N} arbitrary onset threshold as these result in inflated values for time-specific force and RFD.

A problem that currently compromises the accuracy of IMTP force-time data is how the start point of force-time data analysis is identified (8, 9, 23, 26). A stable baseline force and minimal noise is desired during the weighing periods to allow accurate identification of the onset of contraction for IMTP testing (23). However, this will be largely dependent on the administration of strict IMTP protocols and impacted by the participant's pre-tension/contraction and posture and residual noise during the weighing period. Thus, arbitrary and relative onset thresholds should be just high enough to overcome the highest noise level in the participants baseline force to reduce the onset bias and delay in force-time variables analysis (8). In light of this, when using objective automated arbitrary or relative thresholds to determine the onset of the contraction during IMTP, scientists and practitioners should select a threshold which results in low onset bias. The results from this study suggest that BW_{5SD}, $BW_{2.5}$ and BW_{5} are the most suitable objective and relative onset thresholds for calculations of time-specific and RFD values during IMTP testing. However, practitioners should be aware that relative thresholds such as $BW_{2.5}$ and BW_{5} do not consider the noise associated during the weighing periods in contrast to using BW_{5SD}. As such practitioners, can have greater certainty that a deviation in force which exceeds 5 SD of BW is a meaningful change in force (onset of contraction) and not influenced by noise.

The results of this study show that the different onset thresholds influence the force-time variables derived during force-time data analysis which is agreement with previous research (8, 9, 26). Meylan et al. (26) reported similar findings for CMJ kinetic and kinematic variables suggesting that the method of identifying that start of the movement ($BW_{2.5}$, BW_{5}

and BW_{10}) can result in lower or higher of kinematic and kinetic variables. The authors recommended using a $BW_{2.5}$ threshold to preserve as much of the signal as possible; higher thresholds resulted in significant amounts of the eccentric phase being lost in the analysis subsequently impacting kinetic and kinematic variables. Consequently, underestimations of eccentric variables including time to PF, ground contact time, and time to peak power ($p<0.05$) were observed and elevations of concentric variables. Furthermore, Dotan et al. (8) revealed visual, arbitrary and relative determined onset thresholds produced significantly different time to rate of torque development and torque-time plots during an isometric knee extension. The authors also revealed when comparing male boys and men isometric knee extension, the results and magnitude of differences were further influenced by the onset threshold used. Therefore, scientists and practitioners should be aware of the influence of the method used to determine the onset of contraction during isometric assessments and other testing protocols as different force-time kinetics can be attained which subsequently impacts the accuracy of the evaluations of the athlete's contractile properties. Furthermore, caution should be made when interpreting and comparing results between studies who have used different onset thresholds (8, 23).

A potential issue regarding IMTP assessments is reducing the noise associated with participant's pre-tension/contraction and posture during the weighing period to achieve a stable baseline force to subsequently determine BW (average force). Reducing the noise associated during the weighing period can be achieved in several ways including familiarizations with Olympic lifts and the IMTP protocol, visually inspecting the force trace during data collection, and discarding trials with clear fluctuations in force during the weighing period. Achieving a stable baseline force during the weighing period should result in lower standard deviations in BW and subsequently a lower onset threshold and lower onset bias (8, 23). Conversely, relative thresholds fail to consider the noise associated during this weighing period and therefore decrease the certainty that a meaningful change in force has occurred. Therefore, when determining the onset of contraction as a deviation from average BW during the weighing periods, scientists and practitioners are encouraged to familiarize subjects with the IMTP protocol and discard and repeat trials with large fluctuations (peak deviation > 50 N from average BW) and pre-tension/contraction during the weighing period.

It should be noted that there are several limitations of the present study. Firstly, a small sample size (n = 9) resulting in 18 trials were used for comparisons between onset thresholds, while there were also a large number of statistical comparisons. In addition, the present study compared arbitrary and relative BW thresholds to determine the onset of contraction, however a visually and manually determined onset of contraction could produce different results and may reduce onset bias (8, 23). Furthermore, an onset threshold using rate of change in force has been previously used however we did not compare this method (36). It is recommended that further research is required in larger sample sizes and number of trials determining the effect of different onset thresholds on IMTP force-time variables. Future research should compare the $BW_{2.5}$ onset threshold, BW_{5SD} onset threshold, rate of change in force onset threshold as described by West et al. (36), and a manually determined onset threshold to the determine the most accurate and reliable assessment of IMTP force-time variables.

PRACTICAL APPLICATIONS

Overall, this study demonstrated that five different onset thresholds produced different force-time values within a neutral data pool. $BW_{2.5}$ and BW_5 achieved acceptable agreement with

BW_{5SD} and consistently produced the lowest values for time specific-force values and RFD (during 0-100, 0-150 and 0-200 ms); although the best reliability measures were observed with $BW_{2.5}$. Conversely, BW_{10} and BW_{75N} onset thresholds resulted in inflated values for time-specific force values and RFD; while also demonstrating lower reliability measures. These discrepancies can be attributed to the lower onset bias observed with a $BW_{2.5}$, BW_{5SD} and BW_5 threshold which results in the calculation and analysis of force–time variables on a lower portion of the slope of the force-time curve. Conversely, the other onset thresholds have larger onset bias which subsequently results in the erroneous calculations of force-time variables on a higher portion of the force-time curve, thus resulting in elevated values. Therefore, when using automated and objective onset thresholds during IMTP testing, scientists and practitioners are recommended to use BW_{5SD} onset threshold for time-specific force values ($Force_{100}$, $Force_{150}$ and $Force_{200}$) and RFD (RFD_{100}, RFD_{150}, RFD_{200}) for accurate and reliable data, which eliminates the potential influence of noise. As such scientists and practitioners can have greater certainty that the onset of contraction identifies a true meaningful change in force when using this method compared to relative onset thresholds. It is further recommended to keep the threshold of determining the onset of contraction consistent across testing sessions to allow valid comparisons of force-time variables when monitoring and tracking changes in neuromuscular performance.

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